How to Build Valid and Credible Simulation Models

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Outline:

1. Introduction and Definitions

2. Seven-Step Approach for Conducting

a Successful Simulation Study

3. Techniques for Developing Valid

and Credible Models

4. Statistical Techniques for Comparing

Model and System Output Data

1. Introduction and Definitions

Use of a simulation model is a surrogate for actual system experimentation.

If the model is not a “close” approximation to the system, then any conclusions derived from the model are likely to be erroneous.

Basic Premise:

Model building and validation go hand-in-hand.

Verification **(or debugging) is determining whether the conceptual simulation model has been correctly translated into a computer program.**

Validation **is the process of determining whether a simulation model is an accurate representation of the system, for the particular objectives of the**

General perspectives on validation:

- **A “valid” model can be used to make decisions similar to those that would be made if it were feasible and cost-effective to experiment with the system itself.**
- **The ease or difficulty of the validation**

- **A simulation model of a complex system can only be an <u>approximation</u> to the actual system. There is no such thing as absolute model validity, nor is it even desired.**
- **A simulation model should**

- **Validation is <u>not</u> something to be attempted after the model has already been developed, and only if there is time and money still remaining.**

Example 1: Misunderstanding of validation

A military organization paid a consulting company $500,000 for a six-month "simulation study." At the end of the study, a person called us and asked, "Can you tell me in five minutes how to validate our model?"

A simulation model and its results have *credibility* if the "manager" and other key project personnel accept them as "correct."

necessarily credible, and vice versa.

Things that help establish credibility:

- **Manager's understanding of and agreement with the model's assumptions**
- **Demonstration that the model has been validated and verified**
- **Manager's ownership of and involvement with the project**

Accreditation, **which is primarily of interest in DOD, is an official determination that a simulation mo is acceptable for a particular purpo**

Reasons for accreditation:

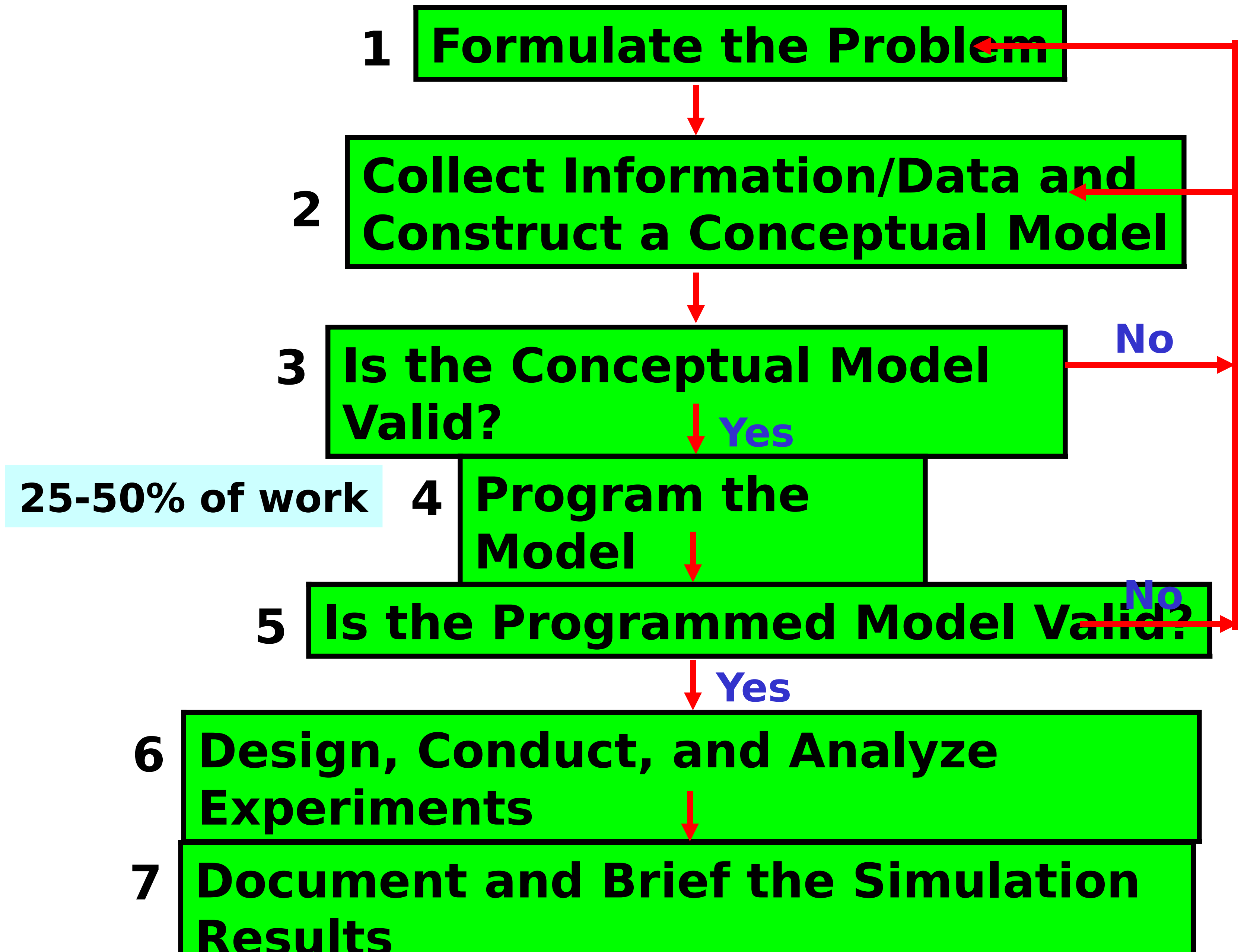
- **Someone must take responsibility for the decision to use a simulation model for a particular application.**
- **Most military analyses are done with legacy simulation models, which may**

The following contribute to the accreditation decision:

- **Validation and verification that have been done**
- **Credibility of the model**
- **Quality of the data that are available**
- **Simulation development and use history**
- **Configuration management including quality of documentation**

2. Seven-Step Approach for Conducting a Successful Simulation Study

See the diagram on the next slide.


1
Formulate the Problem
2
Collect Information/Data and Construct a Conceptual Model
3
Is the Conceptual Model Valid?
No
Yes
25-50% of work
4
Program the Model
5
Is the Programmed Model Valid?
No
Yes
6
Design, Conduct, and Analyze Experiments
7
Document and Brief the Simulation Results

Step 1. Formulate the Problem

- Problem of interest is stated by the

  manager.

- Conduct a kickoff meeting for the

  project, with project manager,

  simulation analysts, and subject-

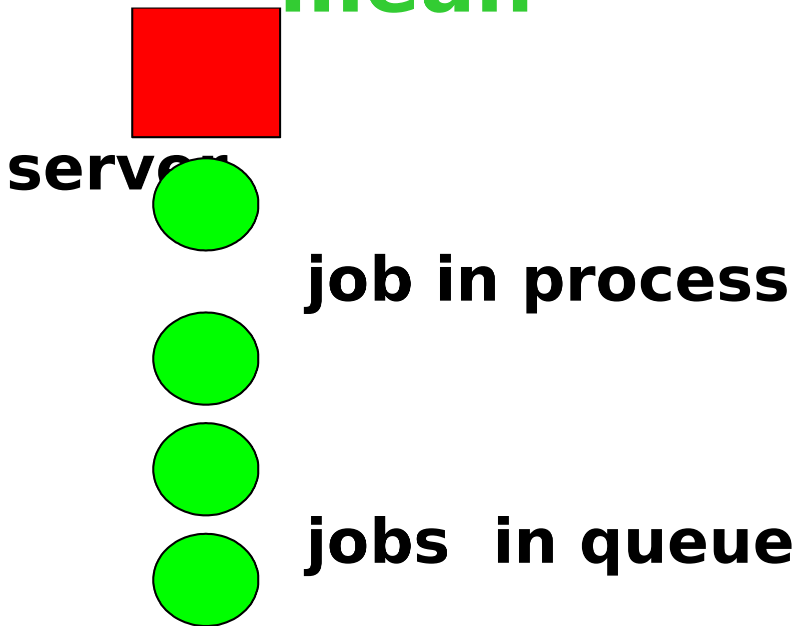
The following are discussed:

- Overall objectives for the study
- <u>Specific</u> questions to be answered
- Performance measures of interest
- Scope of the model
- System configurations to be modeled
- Time frame for the project

Step 2. Collect Information/Data and Construct a Conceptual Model

- Collect information on the system structure and operating procedures.
- Collect data to specify model parameters and probability distributions.

Pitfall: Replacing a distribution by its mean



- Mean interarrival time = 1 minute
- Mean service time = 0.99 minute

Case 1 -- exponential interarrival and service times (actual system)

Long-run average number in queue ≈ 98

Case 2 -- constant interarrival and service times

Number in queue = 0

Conclusion: One must also capture the variability in the input processes.

- **Document the model's assumptions,**
  algorithms, and data summaries in a
  <u>written</u> *conceptual model*.
- **Collect performance data from the**
  existing system (if any) to use for

- **Choosing the level of model detail,**

  which is an art, should depend on the following:

  - **Project objectives**
  - **Performance measures**
  - **Data availability**
  - **Credibility concerns**

- Computer constraints
- Opinions of SMEs
- Time and money constraints

- **There should <u>not</u> be a one to one correspondence between each model element and each system element.**
- **Interact with the manager (and other key project personnel) on a regular basis.**

- **Start with a “simple” model and embellish it as needed. Modeling each aspect of the system might result in:**
  - **Excessive execution times**
  - **Missing important deadlines**
  - **Obscuring important system features**

Step 3. Is the Conceptual Model Valid?

- **Perform a structured walk-through of the conceptual model before an audience that includes the project manager, analysts, and**

- **Correct the (many) errors and omissions discovered in the conceptual model.**

Step 4. Program the Model

- **Decide whether to use a general-purpose programming language or a simulation package.**

  general-purpose programming language:

  C, C++, Java

  Advantages: May already be known, more program control, and lower purchase cost.

General-purpose simulation package:	Application-oriented simulation package:
Arena	OPNET Modeler
Extend	ProModel
SIMUL8	SIMPROCESS

Advantages: Reduced "programming" time and lower project cost

- **Verify simulation program.**

Step 5. Is the Programmed Model Valid?

- If there is an existing system, then

  compare the model performance

  measures for this system to the

  comparable ones from the

  existing

- Regardless of whether there is an existing system, analysts and SMEs should review the simulation results for reasonableness. If results are

- Perform ***sensitivity analyses*** on the programmed model to see which model factors most impact the performance measures and, thus,

Example 2: Subjective probability estimate

Run the simulation with probabilities of kill of 0.70 and 0.80, in addition to the best guess of 0.75.

Step 6. Design, Conduct, and Analyze Simulation Experiments

- For each system configuration, decide on tactical issues such as run length and the number of independent replications.

- Analyze the results and decide if

Step 7. Document and Brief the Simulation Results

- The documentation for the model

  and study should include the

  conceptual model, a detailed

  program description, and the

  results/conclusions for the

- **Final briefing should include animation and a discussion of model building/validation process.**

3. Techniques for Developing Valid and Credible Models

3.1. Formulating the Problem Precisely [1]

Step

- When the manager first initiates the study, the exact problem of interest is sometimes not completely

- **Without a definitive statement of the specific questions of interest, it is impossible to decide on an appropriate level of model detail.**

3.2. Interviewing Subject-Matter Experts [1-2]

- There will never be a single person who knows all of the required information.
- Some of the information supplied

3.3. Interacting with the Manager on a Regular Basis [1-7]

- Helps ensure that the correct problem is solved
- Maintains manager’s interest and involvement
- Model is more credible because manager understands and agrees with model’s

Example 3: Solving the wrong problem

A military analyst worked on a project for months without interacting with the requesting general. At final briefing, the general walked out after five minutes stating, "That's not the problem I'm interested in."

3.4. Using Quantitative Techniques to Validate Model Components [2]

Analyst should use quantitative techniques whenever possible to test the validity of components of the model.

<u>Example 4:</u> Input probability distributions

How well a theoretical probability distribution represents an observed set of data can be assessed by using goodness-of-fit tests and graphical plots.

Comment: Task times will rarely be normally distributed.

3.5. Documenting the Conceptual Model [2]

Components of the conceptual model:

- **Overview section with overall project goals, specific issues, and performance measures**
- **Process-flow/system-layout diagram**
- **Detailed descriptions of each**

- Simplifying assumptions that were made and justification
- Sources of important or controversial information
- Detailed mathematical analyses should be in appendices.

Conceptual model should be a “blueprint” for creating the simulation program, and it should be readable by analysts, SMEs, and managers.

3.6. Performing a Structured Walk-Through [3]

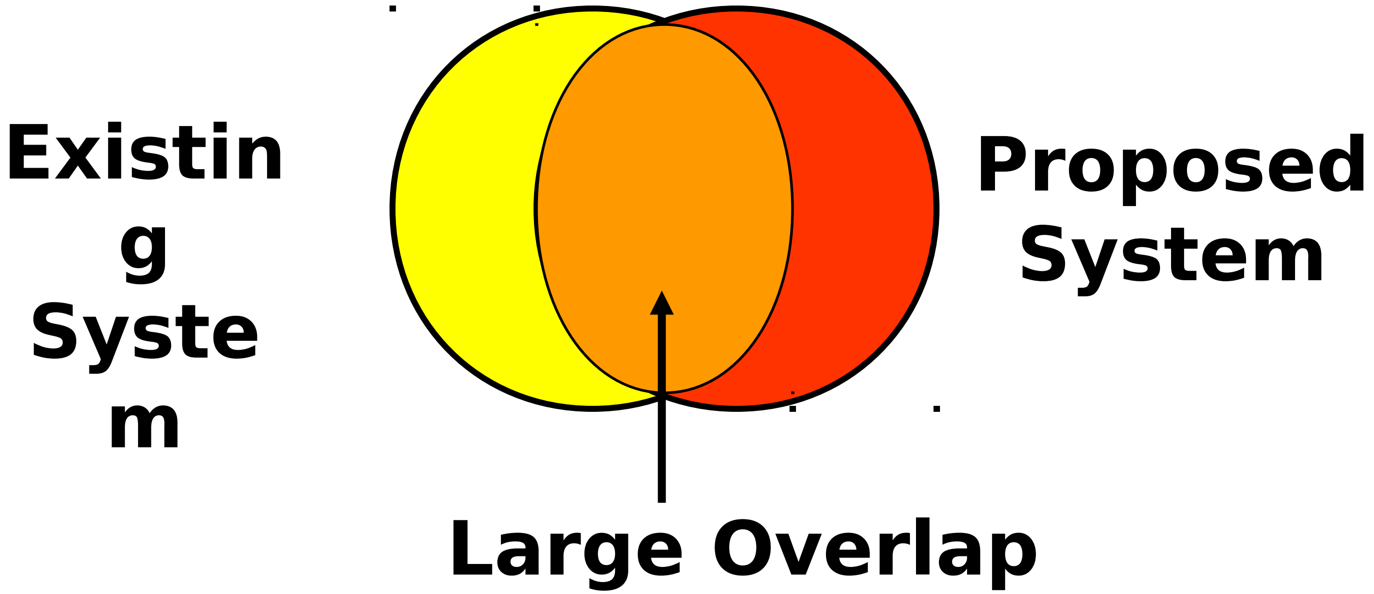
- Helps ensure that the model's assumptions are correct and complete
- Interaction among SMEs is critical
- Promotes ownership of the model
- Takes place before

Example 5: Transportation of crude oil

At a structured walk-through of a transportation system, many important model assumptions were incorrect or missing -- problem was lack of critical SMEs at kickoff meeting.

3.7. Validating the Output from the Overall Simulation Model [5]

- Compare model and system performance measures for the existing system.



Comments:

- **This is the most definitive true validation technique.**
- **In general, it is impossible to validate completely a model of a proposed system.**
- **If this comparison is successful,**

Example 6: U.S. Air Force test agency

Data were available from operations of a bomb wing over a 9-month period, and included component failure data and a wing availability of 0.9.

For the same time period and logistics policy, model produced an availability of 0.873 -- a 3% difference.

Example 7: Validation of Army models

Field-test results for a prototype system are compared to simulation results for certain scenarios.

If the model is "valid" for these scenarios, it is used to extrapolate to scenarios that are infeasible to field test (sometimes called *model-test-model*).

Another validation idea is to compare model results with those from another model known to be "valid."

<u>Example 8:</u> Defense supply center

A new inventory model is to replace an existing one.

- **To validate <u>old model</u>, model orders**

- **To validate <u>new model</u>, the predicted 1998 orders for the two models were compared -- 6% difference.**

4. Statistical Techniques for Comparing Model and System Output Data

It is not easy to use formal statistical techniques such as confidence intervals to compare model and system output data, since these data are each not independent.

Example 9: End-to-end delays for a communications network

System: $E_1^S, E_2^S, \ldots, E_k^S$

Model: $E_1^M, E_2^M, \ldots, E_l^M$

The observations in each data set are not independent.

If we can collect "many" sets of data from the real system, then the following approach could be taken:

Let X_j = random variable based on

***j*th set of system data**

Y_j = random variable based on

***j*th replication of model**

Let $\mu_X = E(X_j)$ and $\mu_Y = E(Y_j)$.

We will try to determine if the model is a "valid" representation of the system by constructing a confidence interval for

$$\zeta = \mu_X - \mu_Y$$

$$Z_j = X_j - Y_j \text{ for } j = 1, 2, ..., n.$$

Then an (approximate) 100(1 - α) percent confidence interval for ζ is given by

$$\bar{Z}(n) \pm t_{n-1,1-\alpha/2}\sqrt{S^2(n)/n}$$

If the interval is centered near 0 and has a “small” length, this suggests that the model is a “valid” representation.

<u>Example 10:</u> Communications network (continued)

Let X_j = average of E_i^Ss in *j*th set of system data

Y_j = average of E_i^Ms in *j*th set of model data

5. Ten Pitfalls in Simulation

1. Failure to have a well-defined set of objectives at the beginning

2. Misunderstanding of simulation by management

3. Failure to communicate with management on a regular basis

4. **Treating a simulation study as if it were primarily an exercise in computer programming**

simulation methodology, operations research, probability, and statistics

6. **Failure to collect good system data**

7. Inappropriate level of model detail

8. Misuse of animation

9. Failure to model system randomness appropriately

10. Failure to perform a proper output-data analysis

Reference:

Law, A. M. and W. D. Kelton, *Simulation Modeling and Analysis*, Third Edition, McGraw-Hill, New York (2000).

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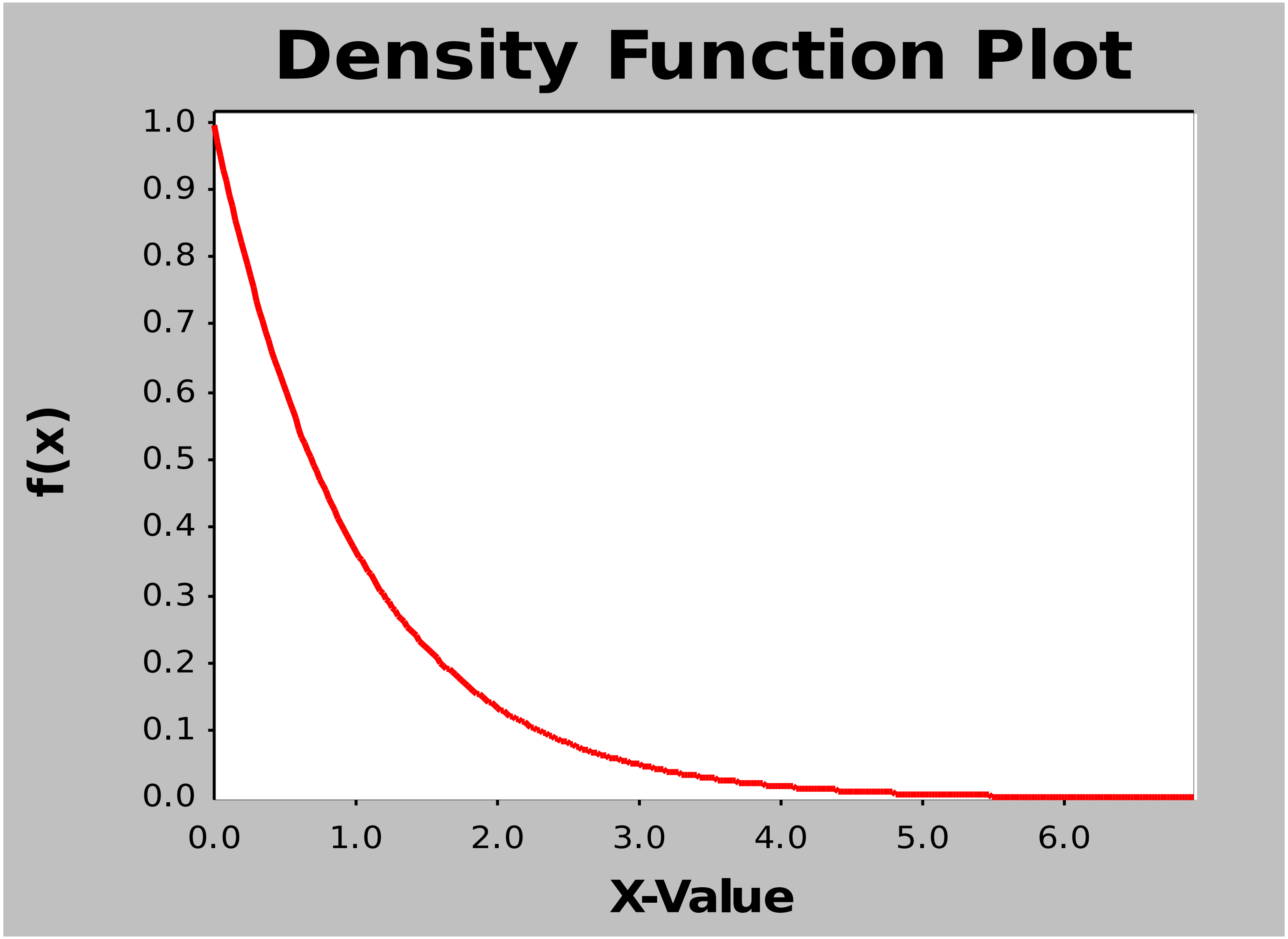
Density Function Plot
f(x)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
X-Value

Return